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attain the completeness of function attained by limbs in the same relative positions with the normal limb extirpated. Although such limbs may be well supplied with peripheral nerves, derived from segments of the cord posterior to the normal limb level, their greatly impaired movements appear to be a consequence of their inadequate supply of central efferent neurones, which run apparently only as far as the normal limb level where they discharge into the somatic motor centers of the normal intact limb.

The generally restricted and non-adaptive movements which these limbs do exhibit upon stimulation are probably effected through more or less imperfectly connected intraspinal, intersegmental correlation neurones of the levels from which peripheral innervation is derived.

A more complete account of the experiments reported in this paper will appear in later publications.

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THE INTERFEROMETRY OF RAPID VIBRATIONS[1] CHIEFLY IN RELATION TO TELEPHONE CURRENTS

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1. *Introductory.*—The preceding apparatus[2] with telescopic or microscopic enlargement of the telephonic vibrations, behaved on the whole so satisfactorily, that it seemed worth while to try a similar design on the interferometer. I was inclined to doubt the feasibility of the plan; but it appeared on trial that the high tension wires actually keep the auxiliary mirrors of the interferometer practically quiet; so that in the absence of alternating current it is not difficult to find the fringes. Tense wires are out of step with the usual laboratory tremors. The system needs no special damping.

The displacement of achromatic fringes due to the induced secondary current is normal to their direction. The objective of the vibration telescope is to oscillate in the direction of the fringes and to be coupled with the primary current. A full account of the changes of phase and amplitude in any transformer system may then be obtained from the fringe ellipses usually seen in the interferometer.

2. *Apparatus. Wide Bifilar.*—This is in large measure a modification of the apparatus described heretofore[3] except that special attachments have been added for sharply reaching the resonance tension of the wire. The latter is shown at $d\ e\ e'\ d'$ in figure 1 (front elevation), being the thinnest steel music wire, about 0.023 cm. in diameter. Its ends are wound around the stiff screws b, b', provided with locknuts, and rotating in horizontal short strong rods a, a', attached to stout standards (not shown) fixed to the bed plate A, B of the interferometer. The wire dd' passed around the grooved pulleys w, w', and above the grooved pulley x, carried in a fork and screw stem y. The latter may be raised or lowered by the nut u, which rests upon the massive carriage BB, supported by the slides AA' of the apparatus. Provision must be made (slotted sheath and pins, not shown) to prevent y from turning on its axis. Tension is roughly given to the wire at the screws b, b', and the fine adjustment is thereafter made at the nut u. This worked very satisfactorily.

The vibrator proper cc' is attached at the middle of the wires d, d', and carries the parallel auxiliary mirrors m, m', of the quadratic interferometer. A thin steel umbrella rib seemed well adapted to fulfill the requirements of cc' though a light soft iron tube would have been preferable.

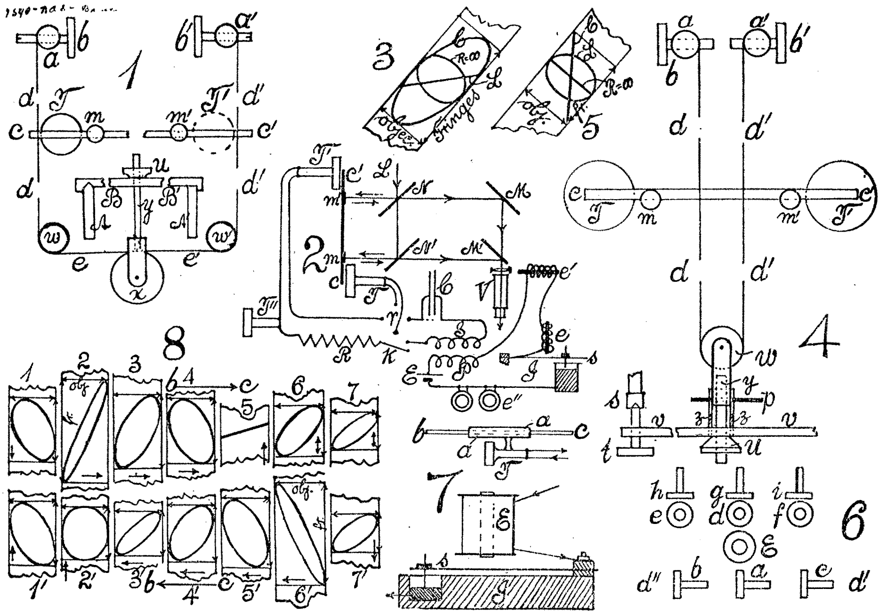
The telephones T and T' are adjustable on special standards, attached to the bed plate (carriage BB) and placed horizontally, one in front and the other toward the rear of the vibrator cc'. It is desirable that one be adjustable on a micrometer screw and spring, so that the distance of the poles of both from cc' may be regulated.

The achromatic fringes in the fine slit image of the telescope field of the interferometer must be observed with a vibration telescope, and it was found desirable to control the latter by a special electromagnet. Figure 2 is a diagram of the parts of the apparatus as a whole, $M\ M'\ N\ N'$ being the mirrors of the interferometer (M' on a normal micrometer screw), m, m' the auxiliary mirrors on the vibrator cc'; T', T, are the telephones (one provided with a switch r), V the vibration telescope, I the mercury interruptor. T'' is an auxiliary telephone for the ear.

The primary consists of the linear coil P described in the preceding paper, the storage cells E (usually four), and the two small electromagnets e, e', for controlling the interruptor and the objective of the vibration telescope, V. The secondary S was the coil "B" of the preceding paper, wound on glass. This was in circuit with a rheostat R (up to 40000 ohms), the telephones T, T', T'', and the key K. The condenser C in the secondary is available when needed, and the inductive resistance e'' in the primary.

The whole of the parts shown in figure 1 could be slid fore and aft on the carriage BB and AA', to accommodate the interferometer.

3. *Observations with the Slit Image.*—It will be seen that if an ordinary telescope is used at V, figure 2, the sharp slit image must widen to a band here, as in the preceding apparatus; but the design is much



less sensitive because the rays are parallel throughout. The slit image nevertheless suffices admirably for finding the resonance tension. For this purpose the screw b or b', figure 1, is first manipulated till the image begins to widen. The fine adjustment is then made at u, y, x, till the maximum band-width is reached. One easily recognizes in this way three harmonics, the fundamental at lowest tension and small band-widths; the octave at larger tension with maximum band-width; and the next overtone at still larger tension and diminished band-width. Above this I did not go as the stress on the wire would have been excessive. The reason for the prominence of the octave here, is not obvious. It does not occur in the later work. While the fundamental showed a band-width of 5 scale-parts, the same for the octave was 42 cm. wide, and for the next harmonic 26 cm. wide.

The remarks made presuppose that the telephones are acting in concert, on opposite sides of the vibrator. We may refer to this as an arrangement in series. When the telephones are acting in opposition, the band-width, s, decreases to one or a few scale-parts, depending on the symmetry of adjustment, etc., which if perfectly made should throw the differential s out entirely.

4. *Observations with the Interferometer.*—As has been stated the fringes are easily found because the rapid motion of the vibrator implies considerable damping. The slit image is thus quite stationary and the fringes clear and strong. On starting the inductor, the fringes at once vanish and after breaking the circuit slowly reappear, unless the vibration telescope is used. When the period of the latter differed from that of the induction (to be very weak), the even band of fringes changed to wave lines travelling in opposed directions and of continually increasing amplitude. Eventually the crests or troughs only are seen and these but on one side (as some micrometer adjustment for one or the other will be necessary to keep them in the field), again travelling in pairs, in opposite directions, through each other. On breaking the circuit these pulses, slowly coalesce into the wave bands and finally into the even band.

The case here presented is that of a relatively slowly vibrating telescopic objective, at V. If the frequency of the latter can be counted, the frequency of the alternator may be deduced from the number of moving crests in the field. Thus when the frequency of the objective was $n' = 5$, there were four crests in motion, implying a frequency of $n = 20$ for the interruptor of the coil. In this respect the case of different periods is advantageous.

The net double amplitude of the waves measured by the ocular micrometer was about 4 scale-parts and $i = 4 \times 10^{-6}$ amperes came to a scale-part, in case of the present small fringes.

The next step in advance consisted in adding an electromagnet, e; figure 2, at the objective of the vibration telescope V, in series with the electromagnet e of the interruptor, I. The two springs at V and I, moreover, were adjusted to about the same period. The electromagnet e' could be rotated on a vertical axis, so that by moving it closer to or further from the steel spring of V, any degree of band-widths was obtainable in the telescope. Magnificent octave fringes were obtained in this way. They moved merely on opening and closing the circuit.

5. Decreased Bifilar Distances.—The easy accomplishment of the above experiments, where the distance between the bifilar threads was about 30 cm. and their length 60 cm., encouraged me to reduce the distances between the threads until the system was virtually torsional. In such a case the displacement at the ends of the vibrating beam (*cc'*, figure 4) is no longer limited to that of the bifilar wires. Figure 4 is a front elevation of the new apparatus; the steel wires *dd'* being at a distance of about 6 cm., their length 60 cm., the distance between the auxiliary mirrors *m*, *m'*, 10 cm., and between the magnets of the telephones *T*, *T'*, 16 cm. The vibrator *cc'* was (as above) a steel umbrella rib. The ends of the wires *dd'* were again wound about the stiff screws *b*, *b'* held in posts *a*, *a'* rigidly attached to the bed plate of the interferometer (not shown). The wires were stretched below by the pulley *w* and screw *y*, controlled by the nut *u* pressing against the rail *v*, also rigidly attached to the bed plate of the interferometer. Provision must be made (slotted sheath *z* and pin *p*) to prevent *y* from turning on its axis. A variety of braces are to be introduced to obviate synchronous vibrations of parts of the apparatus.

The adjustment for resonance is here more difficult than in the preceding case, and *y* must be a fine or a differential screw and the nut *u* work smoothly. Resonance should first be established by aid of the slit image in a telescope with fixed objective and with small resistance (200 ohms) in circuit. After this a large resistance (10,000 ohms and more) may be inserted and the work continued with the interference fringes when further adjustment is possible.

In a later design of the apparatus, the bar *v*, rigidly fixed at one end, was elastically controlled at the other end by the fine threaded screw *t*, pushing against the rigid socket *s*. This is an excellent fine adjustment and when used does not disturb the fringes.

6. Observations with the New Apparatus.—The first trials were made with the white slit image. Using the coil with a virtual electromotive force of about 0.7 volts and a small resistance (200 ohms), the resonance conditions were easily reached in the well-braced apparatus. The resistance was then increased to 10,000 ohms and the corresponding band-width found. When obtained the band-widths *s*, persists. The sensitiveness observed if *s* is 18 scale parts, was $0.7/18 \times 10^{-4} = 4 \times 10^{-6}$ amperes per scale-part (0.01 cm.) of the slit image. Per $\Delta N = 10^{-4}$ cm. of the micrometer of the interferometer, where $b\theta = \Delta N \cos i$ and $\theta = s/2f$ ($f = 23$ cm. being the focal length of the telescope, $b = 10$ cm. the breadth of the ray parallelogram, $i = 45°$), the current would be estimated as 1.3×10^{-7} ampere.

The coil No. 10, with about 90 turns giving 0.001 volts per turn was substituted for *B*. With the ocular micrometer *I* obtained 10^{-7} ampere per scale-part. This is less than what was estimated; but a shortage is here inevitable. The fringes used were fairly large, but completely under control.

Unlike the preceding case, the fringes now obtained were of the elliptic type, so that there is unison between interruptor and vibrator. The ellipses were often magnificent. There was little difficulty in measuring their breadth normal to the direction of fringes when quiet, as this is the fringe displacement. On making or breaking the circuit the ellipses oscillate in the well known way, and it may take a part of a minute or more before they subside into the bands (circuit broken). The ellipses remained in the field with resistances up to 10,000 ohms, below which the ΔN micrometer had to be adjusted to bring either axial extremity into view. Notwithstanding the feeble current, the telephone was still quite audible; so that the sensitiveness of the ear has not been exceeded. When the degree of resonance between the telephonic vibrator and the vibrating objective is exceptionally perfect, marked ellipses may appear in the absence of current, in spite of the fact that the telescope has an independent mounting. This very annoying phenomenon is hard to eliminate.

Another smaller coil with but ten turns giving 0.001 volt per turn was installed with the object of ultimately approaching a condition of silence in an audible telephone. The results were striking throughout but can not be given here.

7. *Capacity and Selfinduction in the Secondary.*—The phase differences thus far observed are attributable to the selfinduction of the secondary. It is interesting therefore to test whether the lead due to capacity can be equally well observed. The circuit, figure 2, was therefore provided with a condensor *C* containing up to one microfarad, in steps of tenths. An auxiliary telephone T'' was also inserted as a detector. The results were successful at once, as shown in figures 3 and 5. In figure 3, $R = \infty$ is the symmetrical ellipse, obtained on open circuit. This changed rapidly into the oblique ellipse *C* when 0.5 microfarads were inserted, and the latter into the bands *L* (with a range of 30 scale-parts) when the circuit was closed with about 3000 ohms. In another adjustment (fig. 5) of primary, $R = \infty$ gave normal bands (i.e., the fringes do not vibrate); the capacity 0.5 microfarads now gave the oblique bands *C* and the selfinduction ($R = 5000$ ohms) the nearly symmetrical ellipse *L*. Space prevents the insertion of other relevant results.

8. Selfinduction in the Primary.—The present experiments contain an element of uncertainty owing to the mechanical (or possibly magnetic) coupling of the vibrator cc', on the interferometer, figure 2, and the objective of the vibration telescope V. I have not thus far been able to eliminate this. Information was sought by inserting additional self-induction into the primary. The two small electromagnets, figure 2, e'', (about an inch long), which could be used either separately or in series, were available for this purpose.

The different elements of harmonic motion involved in the experiment may be analyzed as follows. The whole is fundamentally subject to the vibration period of the spring at the interruptor of the primary, which gives the impressed electromotive force

$$l = l_0 \sin \omega t \tag{1}$$

The current induced in the primary controls the objective of the vibration telescope, which thus moves with a lag α subject to

$$i = i_0 \sin (\omega t - \alpha) \tag{2}$$

and this may be modified by the resistance and inductance in the primary.

The objective is as stated either mechanically or magnetically coupled with the vibrator on the interferometer in a way yet to be ascertained; for each has an independent mounting. Hence the vibrator displacements s are subject to an equation with a lag or lead

$$s = s_0 \sin (\omega t - \beta) \tag{3}$$

in the absence of current in the secondary ($R = \infty$).

Finally the secondary, if carrying current has its own lag or lead γ depending on the R, L, C there inserted, and is thus subject to an equation

$$s = s_0 \sin (\omega t - \gamma) \tag{4}$$

where γ is essentially associated with β, as seen in the preceding paragraphs.

If we suppose the coupling implied in equation (3) to be uniform, the lag in equation (2) may be made obvious.

In these experiments the vibration figures were very large and very definite in the successions of their changes with L, however frequently repeated; but unfortunately the induction in the secondary is soon quenched.

9. Direct Telephonic Induction.—The influence of the oscillating magnetic field on the telephone is much more pervasive than one is apt to suppose. The effect moreover is particularly marked if the telephone is open, i.e. with no connection between the clamps. The stray vibrating field produced by a small electromagnet (say $\frac{1}{4}$ inch iron, 2 inches long) is thus quite audible even beyond 50 cm. from the electromagnet. The degree of response depends moreover on the orientation (fig. 6) of the telephone relative to the electromagnet *E*. If we take the three cardinal positions of the plane of the coil or the diaphragm, the vertical positions *e*, *d*, *f*, and the fore and aft horizontal positions *h*, *g*, *i*, have their maximum response in the plane of symmetry *g d E*. The right and left horizontal positions d'', *b*, *a*, *c*, d', give minimum response (telephone silent) in this plane (*E*, *a*), with maxima at symmetrical positions, *b* and *c*. A convenient reversal of magnetic field is thus obtained.

Although all telephones show the phenomenon pretty well, since it is more distinct on open circuit (which implies a current oscillating from clamp to clamp) it would be well worth while to wind a telephonic bobbin provided with a capacity for the particular purpose of catching the stray magnetic field, such as is here encountered. Without proceeding to this extent, I used the telephone as a secondary as shown in figure 7, where *E* is the electromagnet of the interruptor *I*, *s* being the vibrating break circuit spring. The telephone depending adjustably from the sleeve *a* may be slid right and left or rotated into any horizontal position relative to *E*, and the current obtained measured by the vibrator.

In the endeavor to minimize the mechanical coupling, the telescope (separately mounted) was placed at about a meter from the vibrator. In this case the phase difference of the vibrations of fringes and objective was annulled, but the bands in the absence of current were nevertheless somewhat oblique to the direction of the vibration of the objective, showing that the fringes still vibrated.

With this exception the behavior of the telephone inductor was admirable. In passing from the positions *b* to *c* by sliding the telephone, the ellipses regularly passed through the oblique bands, indicating that these successive ellipses, even if of nearly equal size, were opposite in their phase rotation. This was the case when the secondary was closed with 5000 ohms and the inevitable inductance; also when a capacity was placed in the secondary and finally on passing from an inductance to a capacity in the secondary. The effect produced by changes of capacity of 0.5 microfarad was marked. The alternate-current effect, moreover, was still apparent when the circuit was closed with 25,000 ohms and the telephone practically silent.

The most direct criterion as to changes of phase is the rotation of ellipses as indicated in figure 8. I shall give a few examples of what is observed in the telephone displacement in question.

In the absence of current the fringe bands were nearly horizontal parallel lines. The secondary was closed with 5000 ohms and the inductance of the three telephones. From the position *b* (ellipse 1, figure 8 quiescent) the inductor telephone was quickly displaced to position *c*. The enormously eccentric, finally linear ellipse, 2, follows, which then rotates and contracts counterclockwise through the figures 3 and 4 into the sharp bands (usually but not always) no. 5. These duplications then separate on further rotation into the final quiescent form, 7. The arrows indicate the drift of one of the four points of tangency. On returning from *c*, by quickly sliding the telephone inductor into the position *b*, the figures roll clockwise from 7′ to 1′. Number 7′ passes at once through the highly eccentric ellipse 6′, though in other slower adjustments intermediate sharp duplicates like 5 may be detected between 6′ and 7′. The stretched ellipses, which follow immediately after the change of aspect of the telephone bobbin to the magnetic lines, are noteworthy. They result from the sudden reversal of the magnetic field in spite of the vibration. Ellipses cross over or change sign of rotation at 2 and 6′, but not near 3′or between 5, the latter being oscillations. The corresponding cases for capacity, were similar on the whole, though less pronounced. Moreover the first and final forms were not quite in opposed phases.

10. Narrow bifilar.—After obtaining the favorable results just described, it seemed obvious that the sensitiveness could be further increased by diminishing the distance between the bifilar wires. Accordingly, with the same inductor, figure 4, the above wires (diameter 0.023 cm.) were adjusted at but 1.5 cm. apart by decreasing the diameter of the lower pulley. A few other modifications were added. The results however were disappointing throughout.

A final observation may be added. The auxiliary audible telephone responded with about equal loudness when the telephone circuit was closed with 400 ohms and when a condenser of 1 microfarad capacity was inserted. But the vibrator reacted in the former case (resistance and selfinduction) with a deflection of 23 scale-parts, whereas in the latter (capacity) the response was at most 2 scale-parts; and this required a slightly different tension of wire. The metallically closed circuit therefore affected the vibrator at least 12 times more strongly than the oscillation due to the capacity of 1 microfarad. Small capacities like 0.1 microfarad fail to influence the vibrator though to the ear the sound is quite loud. The capacity should have to be increased to 10 or 20 microfarads for equal effects on telephone and vibrator. In another experiment the closed circuit gave 20 scale-parts. The insertion of 4 microfarads decreased this to 4 scale-parts, which is again a demand of about 20 microfarads for an equality of behavior. On the other hand, while the telephone responds for a phenomenally small capacity, it soon ceases to increase in loudness (for 1, 2, 3, 4, mf., or resistances), whereas the deflections of the vibrator increase regularly.

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[1] Advance note from a Report to the Carnegie Institution of Washington, D. C.

[2] These PROCEEDINGS, **5**, 211–217, (1919).

[3] These PROCEEDINGS, **4**, 328–333, (1918). Carneg. Publ. No. 249, **3**, 1919, chap. v.

ON THE PRESSURE VARIATION OF SPECIFIC HEAT OF LIQUIDS

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1. Introductory.—The measurement of the specific heat of a liquid in its relation to pressure is surrounded by so many difficulties, that any method which gives a fair promise of success deserves to be carefully scrutinized. During the course of my recent work on interferometry, I have had this in view, and the plan which the present paper proposes is particularly interesting as it seems to be quite selfcontained.

2. Equations.—If θ, p, ρ, c, denote the absolute temperature, the pressure, the density, and the specific heat at constant pressure, respectively, of the liquid, and if $\alpha' = (dv/v)/d\theta$ is its coefficient of volume expansion, the relation of these quantities may be expressed by the well known thermodynamic equation

$$d\theta/dp = \alpha'\theta/J\rho c \tag{1}$$

where J is the mechanical equivalent of heat, and the transformation is along an adiabatic. The main difficulty involved would therefore be the measurement of the temperature increment; for dp could be read off on a Bourdon gauge after a partial stroke of the lever of my screw compressor, with facility. It is my purpose to find $d\theta$ by the displacement interferometer. To fix the ideas; suppose the liquid in